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Humidity and Temperature Sensors on Plastic Foil for Textile Integration

C. Ataman[a] *, T. Kinkeldei[b], A. Vasquez-Quintero[a], F. Molina-Lopez[a], J. Courbat[a], K. Cherenack[b], D. Briand[a], G. Tröster[b], N. F. de Rooij[a]

[a]*Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Sensors, Actuators and Microsystems Laboratory (SAMLAB), Neuchâtel, Switzerland*

[b]*Eidgenössische Technische Hochschule Zürich (ETHZ), Electronics Laboratory, Zurich, Switzerland*

Abstract

Low-power humidity and temperature sensors fabricated on Kapton® polyimide sheets are successfully woven into textile using a conventional weaving machine. During machine weaving electronic devices undergo mechanical deformation, mostly due to bending, and shear forces. Bending radii in textiles can be as small as 165 µm during weaving, corresponding to a strain of about 15 %. This imposes stringent mechanical requirements on the textile integrated sensors. In this work, we present gas sensors on plastic foil with encapsulated active area for protection during stripes dicing, weaving, and operation. Basic tests with CAB and PDMS sensing layers on capacitive transducers showed that woven sensors survive the weaving process without loss of functionality.

"Keywords: gas sensors; flexible sensors; textile integration; woven sensors"

1. Introduction

Electronic textiles have a wide range of potential use in wearable computing and large-area applications, including medical monitoring [1], assistance to the disabled [2], and distributed sensor networks [3]. The spectrum of e-textiles ranges from wearable electronics attached to textile substrates to electronic components integrated directly with the textile yarn. This introduction of electronics at the yarn level is considered to be the next step in the evolution of e-textiles and brings electronic-textile integration below the device-level. While flexible pressure and temperature sensors for textile integration are relatively easy to realize, gas sensors are more challenging due to their more complex structure involving

* Corresponding author. Tel.: +41-32-720-5357 ; fax: +41-32-720-5754 .
E-mail address: caglar.ataman@epfl.ch .

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gas sensitive materials that must have access to the external environment. Recently, flexible and light-weight gas sensors on plastic foils have been reported by EPFL [4-5]. They can be produced using a simple process and take advantage of the plastic substrate reactivity to enhance sensing performances. Based on this technology, we hereby present the design, fabrication and characterization results for a mechanically robust thin-film capacitive gas sensor platform compatible with an industrial weaving process.

2. Design and fabrication

2.1. Sensor structure

The multilayer sensor structure is depicted in Fig 1a, with a magnified view of the central active area. The 6 cm long and 2 mm wide slender design allows the sensors to be easily fed into the weaving machine. During an industrial weaving process, the thread goes through significant bending, with radii of curvature as small as 165 µm. This imposes the choice of a soft substrate for the sensor platform, which is a 50 µm thick Kapton E film in our case. A thin sensor also ensures the preservation of textile flexibility after the sensors are woven. The sensing elements are located within the central 1.6 x 1.6 mm^2 area, and consist of an interdigitated thin-film capacitor coated with a humidity/gas sensitive polymer, and a temperature sensitive thin-film line-resistor. The design variants with 5 µm and 10 µm line-widths were successfully fabricated. The presence and/or the concentration of the target gas can be monitored through the change in the capacitance, which is a manifestation of the concentration dependent permittivity of the sensing-layer. The single line connecting the E_2 and E_3 electrodes functions as the resistive temperature sensor. For protection during the weaving process and after, the active area is encircled by a dry foil film and encapsulated by using gas-permeable porous Teflon film.

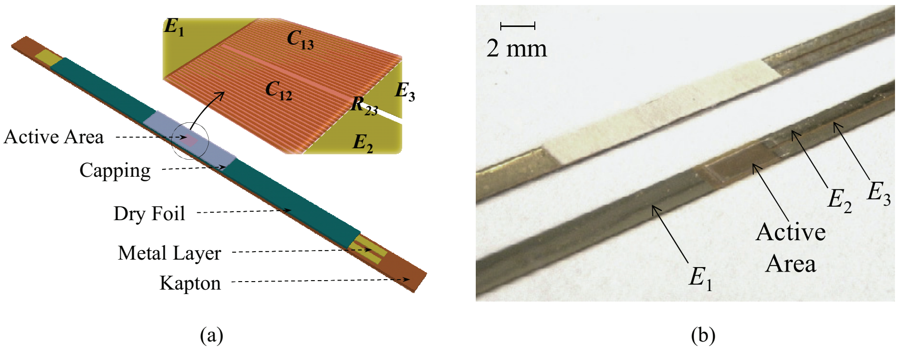


Fig. 1. (a) 3D depiction of the multilayer sensor structure and the active area coated with the sensing polymer. (b) Pictograph of the gas sensors with and without the Teflon capping layer.

2.2. Fabrication process

Major steps of the fabrication process are depicted in Fig. 2a. The process starts with the cleaning and oxygen plasma treatment of the 50 µm thick Kapton E foil, and continues by the formation of the 5/100 nm thick Cr/Au metal structures via a lift-off process (Fig. 2a.b). Next, the 50 µm thick dry photoresist film (DuPont PerMX 3050) is laminated using a semi-automatic lamination tool. The lamination temperature is 85°C, the roll pressure is 2 bars and the lamination speed is 0.2 m/min. A standard lithography process is used to pattern the dry photoresist film and to uncover the central active area and the interconnect ends (Fig. 2a.c). The 10 µm (nominal) thick gas sensitive polymer (PDMS or CAB for proof of concept) is then drop-coated locally or spray-coated through a stencil mask onto the capacitors (Fig. 2a.d). The capping layer, a gas permeable porous Teflon layer with 135 µm thickness, is laminated onto the dry foil layer via the ARclear® 8932 adhesive film (Fig. 2a.e). The protected sensor stripes are then diced using a standard IC dicing tool. Finally, a NFREQ 42 machine from Müller Frick was used to wave the sensors into a 45 mm-wide and 200 mm-long textile band in weft direction with twill (1/8) weave pattern [6]. The woven sensors, with and without the Teflon capping, are shown in Fig. 2b.

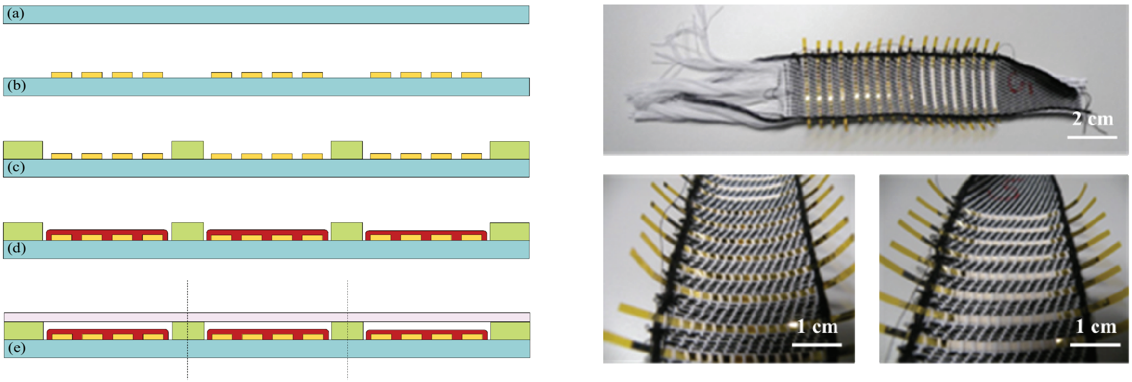
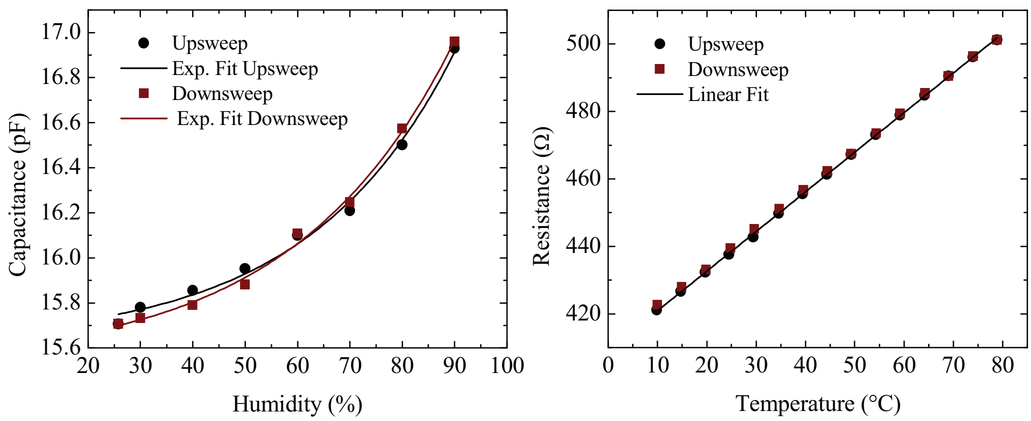


Fig. 2. (a) Sensor fabrication steps. (b) Images of the woven sensors with and without the Teflon capping layer.

3. Test and characterization

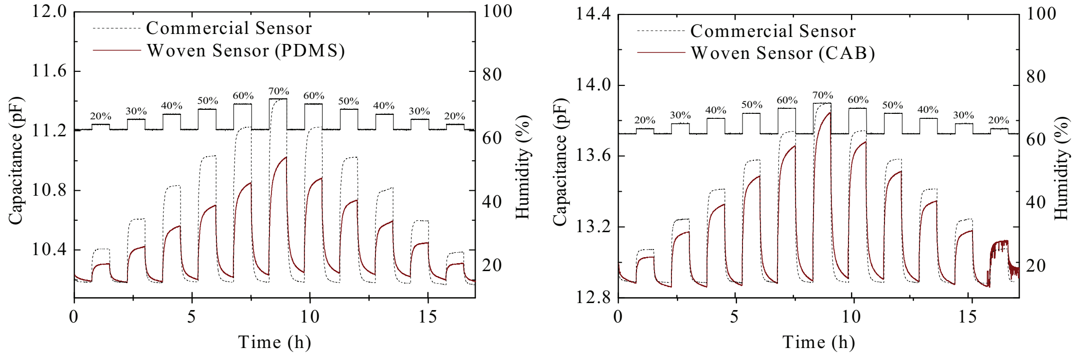
The sensors were characterized for humidity response with PDMS and CAB sensing layers. Fig. 3a shows the humidity sensing behavior of the woven gas sensors with PDMS sensing layer, measured under constant 25°C ambient temperature. The sensing capacitance has a raised exponential dependence on the ambient humidity. The integrated temperature sensors, as shown in Fig. 3b, have a linear sensitivity of 1.175Ω/°C, which corresponds to a TCR of 2701 ppm/°C.



(a) (b)

Fig 3. (a) Basic humidity sensing behavior of the woven gas sensors with PDMS sensing layer, measured under constant 25°C ambient temperature (b) Basic temperature sensing behavior of the integrated temperature sensor, measured under constant 30% ambient humidity. The slope of the linear fit is 1.175 Ω/°C.

The transient capacitance behavior of woven sensors with PDMS and CAB sensing layers are depicted and compared with a commercial humidity sensor output in Fig. 4a and b, respectively. Experiments were performed within an isolated chamber, in which the humidity was controlled via continuous flow of the carrier gas (nitrogen + humidity) at 500 sccm. Capacitance values are monitored with an Agilent E4980A LCR meter. The sensors exhibit a repeatable and reversible behavior, which is in good agreement with the reference commercial sensor, while CAB exhibits significantly higher sensitivity. However, in both cases, the response times of the woven sensors are significantly longer compared to the commercial sensor, and they grow with increasing humidity cycle depth, which is a manifestation of the exponential dependence of the capacitance to the ambient humidity (Fig. 3a). The response time of the sensors can be improved by tailoring the humidity absorption properties of the sensing layers.



(a) (b)

Fig. 4: Dynamic response of woven sensor capacitance with PDMS (a) and CAB (b) sensing layer, compared to a Sensirion SHT15 commercial humidity sensor. N_2 with different humidity levels was used as carrier gas with a total flow of 500 sccm. The percentage values on the plots refer to the amount of humidity in the carrier gas.

4. Conclusions

A robust and reliable platform for textile integrated low-cost and low-power gas sensors were fabricated and characterized for humidity sensing as proof-of-principle. Despite the invasive weaving process, woven sensors remained operational after textile integration, and exhibit good sensing behavior. The developed platform is particularly interesting for textile integrated arrays with individually functionalized sensors to perform complex sensing tasks.

Acknowledgements

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